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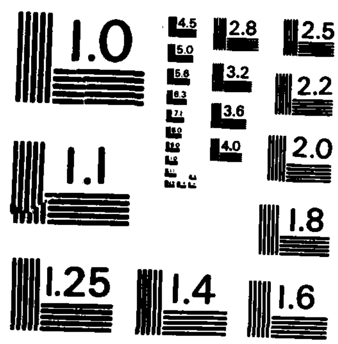

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A Few Points on Longitudinal Jet Ejection Techniques /24

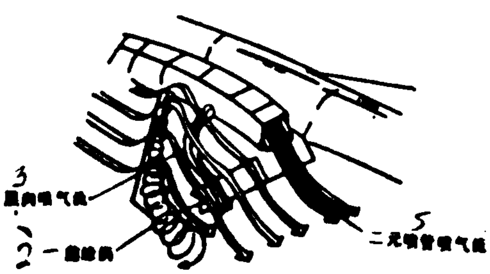
By Tien Shey-Shi

Research in the area of dynamic lifting techniques has had many years of history. In the early days, this was limited to the study of associated surface layer control techniques such as jet ejection at the ailerons, jet ejection at the associated surface layers, and the mechnisms of aileron jet ejection. Presently, this research has advanced to various programs of more practical value such as the blow-in type ailerons, the blow-out type ailerons, top-surface ejection, powered wings, and vector thrust designs. Among these, the blow-in type ailerons have been successfully used in fighter jets such as the F-4's and the MiG-21's; the blow-out type ailerons were employed in YC-15; top-surface ejection technique was used in YC-14; the powered-wing design was implemented in the United States C-5A and the Canadian DHC-5 planes and has demonstrated its great potential. As to the vector thrust design implemented in the U-model planes, its unique capabilities have been demonstrated and are well known.

In recent years, research has pressed ahead both within China and abroad on the applicability of advanced lift-enhancement techniques such as the duplex jet ejection pipes, the various induced ejection techniques, the serially-arrayed-fans engines, and longitudinal jet ejection techniques. This paper expresses some of my personal views on the current state of this research, the feasibility and practicability of longitudinal jet ejection techniques.

Research in the control of the longitudinal vortex at the aircraft wings by means of longitudinal jet ejection was started abroad in the 60's. The direction of this research was soon turned to the search for a possible means of employing this technique to improve the characteristics of aircraft approaching angles. But the jet generated by a state-of-the-art engine gas compressor was far from sufficient to satisfy the requirements for a desired ejection performance. This requirement can only be met if the exhaust jet of the turbo is utilized. For this reason, progress in this research was slowed down for a while. After the 70's, the relatively greater advancements in other areas of dynamic lift enhancement studies have led researchers to consider the possibility of joint application of longitudinal ejection techniques and other dynamic lift-enhancement measures. In addition, it was discovered that when jet streams from the engine's gas compressor are ducted to the control surfaces such as the ailerons, the trailing edges and the rudder surface, the ejection performances can be much more pronounced than jet ejection on the main wings because of the smaller surface areas of these control surfaces. Hence research in this area became active once again and exciting progresses have been made.

4 综合吹气技术 (VEO机翼)

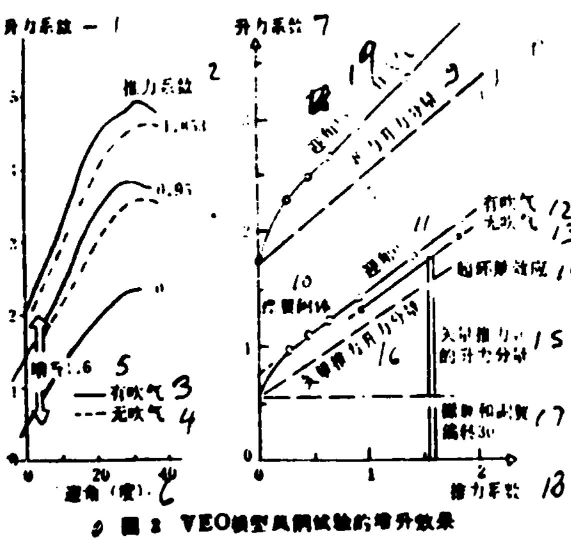


2 leading edge vortex
3 longitudinal jet stream
4 combined jet ejection techniques (VEO Wing)
5 duplex ejection pipe jet stream

Figure 1 American VEO Wing Concept Schematic Diagram

The "wing-top vector engine" (VEO) wing jet ejection design that has been studied abroad since the mid 70's is a design that combines organically several dynamic lift enhancement techniques such as the wing-top longitudinal jet ejection, the duplex jet ejection pipes, the vector propelling forces, and the super-periphery jet ejection ailerons. Figure 1 is a VEO design proposed by USA NASA for next generation fighter jets. The engines are located at the base of wing top surfaces. The duplex jet ejection pipes with a width:length ratio of 4∿6 are located at the junction of the wings and the trailing edges. Outside the orifice of each ejection pipe is a flexible half-pyramid shaped blockage which is used to change the downward deflection of the jet stream. This blockage also makes the ejection pipe have the shape of a Lavalle's duct. Because of the great thrust of the engine-tail jet stream, a relative small deflection angle ($<$ 15 degrees) of the jets will be sufficient to achieve a noticeable super-periphery effect without causing a significant loss to the engine's thrust. Another feature of this design is that a portion of the exhaust jet is utilized to eject longitudinally from the base of the leading edge to enhance the leading edge vortex. This combined jet ejection (jet blowing) implementation has a high lift-enhancement performance. Figure 2 shows the test results of this model tested in the 40 x 80 feet^2 wind tunnel of NASA's Ames Research Center. The individual contributions of each of the lift-enhancement measures and their combined performance

can be clearly observed in this figure. Among these, the induced lift enhancement from longitudinal jet ejection can reach 32% with the ejection thrust being 16% of the total engine thrust. NASA's Langley Research Center conducted comparative studies of pure transversal jet ejection, pure longitudinal jet ejection and the combination of the two techniques based on the VEO wing design. It was discovered that there exists synergistic aerodynamic interference between the transversal jet ejection and the longitudinal jet ejection. The lift enhancement of the two techniques combined exceeds the sum of the lift enhancements by each technique alone. The lift enhancement due to this interference constituted about 40% of the total lift enhancement achieved.



1,7 lift coefficient
2,18 propelling coefficient
3,12 with jet ejection
4,13 without jet ejection
5 lift enhancement
6, 11 aircraft approaching angle
9 lift projection of the vector thrust
10 aileron associated objects
14 super-periphery effect (?)
15 lift projection of the vector thrust, 40 degrees
16 lift projection of the vector thrust
17 aileron and trailing edge deflected by 30 degrees
19 aircraft approaching angle at 15°, with jet ejection

Figure 2 Lift Enhancement Performance of a VEO Model in Wind Tunnel Tests

STUDIES IN LONGITUDINAL JET EJECTION AT THE AILERONS

The United States of America started the studies of the aerodynamic potentials of longitudinal jet ejection on the control surfaces back in 1970. It was discovered that in a canard configuration, longitudinal ejections at the leading edges or at the ailerons can produce a strong lifting force which can help to solve the vertical imbalance problem caused by the lift enhancement designs at the main wings. Longitudinal jet ejection at the rudder can increase the maximal deflection angle of the rudder plate. Of these, the most pronounced effect was demonstrated by longitudinal jet ejection at the ailerons.

Dixon of the United States once used a rectangular flat board model of the aircraft wing and a 1:4.65 scaled model of the F-8J to perform a series of experiments on longitudinal jet ejection at the ailerons. His results showed that in an aircraft landing configuration, (approaching angle 12^{o}, aileron deflection 40^{o}), the longitudinal jet ejection at the ailerons (ejection coefficient 0.014) can increase the lift by 12%. The U.S. Naval Boats and Ships Research Center used a 1:5 scaled model of F2C to experiment with aileron longitudinal jet ejection designs. Their results showed that in a landing configuration, the lift enhancement can be up

to 2.4% when the ejection coefficient is 0.012.

Compared to the aileron transversal ejection design, the longitudinal jet ejection at the ailerons has the advantages that the design is simpler; it requires less added weight; it does not take up any space inside the wing compartment; and it has a higher battle survivability. It has the potential to compete with aileron transversal jet ejection techniques for lift enhancement in a landing configuration (when engine thrust requirement is less severe). Furthermore, as engine performances are improved in the future there will be sufficient exhaust jet available for ejection and aileron longitudinal ejection will be even more significant. This is because it is extremely difficult to eject the exhaust gas from the ejection seams along the wing span (seam width is only 2mm) in a transversal ejection setup. In addition, when exhaust is utilized the ejection coefficient can be higher than 0.01; under such circumstances the surface-layer control mechanism of aileron transversal ejection will have reached its peak performance while there will still be reserve in the vortex-control mechanism of the aileron longitudinal jet ejection design.

Not long ago NASA's Langley Center was again testing a model of aileron bottom-surface longitudinal ejection in a low speed wind tunnel. (See Figure 3. Also, Volume 83, No. 2 of this Journal). In this model, there is an engine

on each side of the fuselage, with a 45° downward deflected duplex tail ejection pipe. On each side of the aircraft rear end there is a gridded longitudinal ejection orifice located on the anterior edge of the aileron's bottom surface. This allows the jet to be ejected along the junction seams. It was found that the induced effect by the engine's tail pipes alone can produce an increase in lift coefficient by 0.1. The induced effect of the aileron jet ejection alone can produce an increase in lift coefficient by 0.16. However, when both ejection mechanisms were employed the total induced increase in lift coefficient is 0.43, which acounts for 18% of the total lift force (2.34).

COMPARISON OF PRACTICABILITIES OF VARIOUS EJECTION DESIGNS

Among WEO combined lift enhancement, aileron top-surface longitudinal ejection, aileron bottom-surface longitudinal ejection, and aileron transversal ejection designs, which is the more desirable? The answer to this question will depend on individual applications. If the objective is to achieve an improved dynamic performance in aircraft approaching angle, and the aircraft is to fly in high sonic conditions, then aileron deflection angle cannot be too large ($<20^{\circ}$). In this case, the lift enhancement capabilities of the various aileron jet ejection designs will all be greatly reduced since lift enhancement is mainly realized through the super-periphery effect. Even the longitudinal ejection design will require

a greater ejection coefficient. The VEO combined design will then be the only one with some potential. If the objective is to improve aircraft landing performance, then any of the four designs will be applicable. The choice will depend on the engine performance and the aircraft lift enhancement requirements.

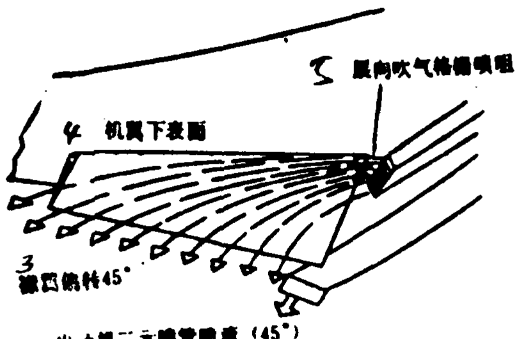
Generally speaking, aileron transversal jet ejection design has a very limited lift enhancement capability. Furthermore, it cannot utilize the engine's exhaust gas. The lift enhancement ratio of this design can rarely exceed 20-30%. However, this design requires less jet ejection. Aileron top-surface longitudinal ejection can achieve a higher lift enhancement; it makes use of the engine's exhaust. A combined lift enhancement technique employing both the aileron bottom-surface longitudinal ejection and the duplex ejection pipes, and the VEO combined ejection technique can both achieve a lift enhancement ratio of 40%. However, the lift enhancement effect is prominent only when there is high ejection power. Regrettably, we have yet to see any publication on a jet ejection design that combines aileron top-surface ejection and duplex-pipe ejection. But it is obvious that in a landing scenario it will be difficult for any of these designs to achieve a lift enhancement ratio exceeding 40%, that is, lift coefficient increased by 0.6.

It is thus concluded that the vector thrust technique will be the only resort for the realization of 300-meter runway landing (approaching lift coefficient must be in the order of 2.5) for next generation fighter jets .

RESEARCH IN LONGITUDINAL JET EJECTION WITHIN CHINA

In recent years, we have also started experiments to study the mechanism of longitudinal ejection and its applicability. A triangular winged aircraft model was used in the wind tunnel experiments of longitudinal/transversal ejection designs. Results of aileron longitudinal jet ejection experiments indicated that when the ejection coefficient is 0.12, an aircraft in landing configuration can have a lift enhancement ratio up to 20%. This is comparable to what can be achieved by aileron transversal jet ejection. It should be pointed out that the ejection coefficient mentioned above is what is realizable by state-of-the-art engine compressors in landing scenarios. However, with smaller ejection coefficients, the longitudinal ejection design is far less effective than the transversal ejection design. This has to do with the mechanism of aileron longitudinal ejection techniques. There exists scant published reports from foreign countries regarding this problem. Dixon was the only one who has given any explanations. He believed that similar to the

main-wing longitudinal ejection, the aileron top-surface longitudinal ejection will cause the formation of an "ejection vortex". But the main reason for aileron lift enhancement is the change of the wing-surface wash-stream field caused by the interference of the ejection stream and the main stream. The longitudinal ejection stream will carry the stream coming from the front and move toward the wingtips with a big deflection angle. The combined streams move outward and backward along the wing surface. Dixon thus believed that aileron longitudinal ejection is different from the main wing longitudinal ejection; the latter belongs to the topic of vortex control, whereas the former belongs to the topic of associated surface-layers control. However, our experiments have demonstrated that the vortex control effect is also manifested in aileron longitudinal ejection. Figure 4 shows the pattern of oil flow in the aforementioned rectangular aileron on a triangular winged model under longitudinal jet ejection. The picture was taken when the aileron was deflected by 45°. It is clear that the jet streams were divided even before the ejection. An extended concentric vortex appeared in front of the ejection stream after the jet ejection. Note that the vortex is located in front of the ejection stream; it is clearly not the "ejection vortex" commonly attributed to the interference of the ejection stream with the main stream. Further studies

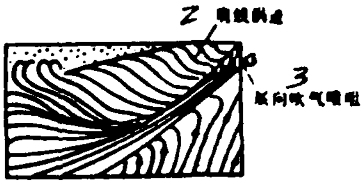


1 图 3 美国副翼下表面展向吹气模型示意图

2 engine duplex ejection pipe ejection stream (45^{o})
3 aileron deflected by 45^{o}
4 wing bottom-surface
5 longitudinal ejection gridded orifice

1 Figure 3 American Aileron Bottom-Surface Longitudinal Ejection Design Schematic Diagram

1 图 4 副翼展向吹气试验模型上的副翼油流谱图



2 shoulder seam vortex
3 longitudinal ejection orifice

1 Figure 4 Aileron Longitudinal Ejection Experiment, Oil-Flow Spectrum

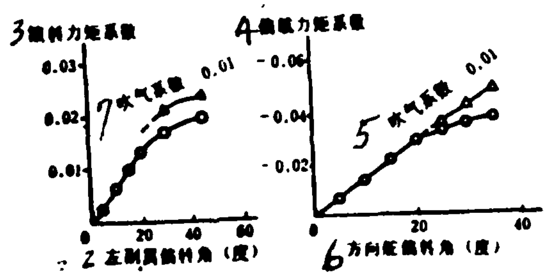
indicated that this vortex comes from the division of streams at the shoulder seam of the aileron. These divided streams are carried by the ejection stream which provides them with a radial velocity, and equips them with the right conditions for the formation of a stable triple vortex. This vortex can thus be called the "shoulder seam vortex". It is this vortex that affects significantly the aileron and the main-wing flow fields. For this reason, the aileron top-surface longitudinal ejection lift enhancement cannot be attributed entirely to the associated surface-layer control mechanism of the ejection stream; the vortex control mechanism must also be accounted for.

Using the same model, we also performed small-ejection-coefficient longitudinal ejection experiments on the rudder, the elevator, and the horizontal stabilizer. The purpose is to verify the effectiveness of these measures under the ejection conditions of state-of-the-art aircraft engines. The results indicated that except for the horizontal stabilizer longitudinal ejection, which was demonstrated to be effective, longitudinal jet ejection on the rudder and on the elevator both significantly increased the extent of the rudder orientation (Figure 5). In Figure 5, it can be observed that the performance curve of the rudder remains linear even when the rudder orientation angle exceeds 35°. The effectiveness is high even when the deflection angle of the

elevator is greater than 30°. The results also showed that when the elevators on both sides are used as secondary ailerons, the lift enhancement can be up to 20%.

As next-generation fighter jets are likely to have even thinner wings, the space within the wing compartment will be more and more limited. This not only minimizes the possibility of implementing aileron transversal ejection design, but the open-seam type of aileron will also be not suitable. Thus longitudinal jet ejection for lift enhancement purposes becomes more and more appealing. With the advancement in the fabrication of advanced high thrust-weight-ratio engines, this design also becomes more practicable. In addition, Dixon of the United States and Poisson of France have both shown that with main-wing longitudinal ejection (ejection coefficient 0.003-0.005) on supersonic airplanes, the shock-wave induced separation can be controlled, the vibration magnitude can be reduced, and the radial lift coefficient can be increased by 16%. It is forseeable that longitudinal jet ejection and some combined techniques employing longitudinal ejection are going to gain wider utilization.

Under the current circumstances, the engine performance cannot meet the requirements of main-wing longitudinal design; it is expected that longitudinal jet ejection at control surfaces such as the ailerons, the elevators, the rudder, etc., will be utilized in the near future, since these measures are practicable and highly effective.



1 图 5 副翼和方向舵展向吹气试验的效果

2 left elevation deflection angle (degrees)
3 rotating arm coefficient
4 translation arm coefficient
5,7 ejection coefficient
6 rudder orientation angle (degrees)

1 Figure 5 Elevator and :udder Longitudinal Ejection Experiment Results

GLOSSARY

Ejection Coefficient--

This is a zeroth-order characteristic parameter related to jet ejection techniques. (both longitudinal and transversal jet ejection). Commonly denoted by C_{μ}, it is defined as

$$C_{\mu} = \frac{m_j \, v_j}{q \, s}$$

where the subscript j indicates the parameter values measured at the orifice of jet ejection. m_j is the total mass flow of the jet stream at the orifice. v_j is the jet stream velocity at the orifice. q is the dynamic pressure of the jet stream coming from the front of the aircraft. s is a reference area. (The wing area is commonly used for s). Obviously, the value of this parameter is determined by a combination of factors such as the geometric features of the jet pipe, the jet stream properties (e.g., temperature, flow and pressure ratio, etc.). In experiments with jet ejection models, this parameter must also be satisfied. Generally speaking, there is a maximal value of C_{μ} (about 0.01) in jet ejection control of associated surfaces. Any design with a C_{μ} value greater than this maximum will be referred to as an ejection control technique; with the ejection the lift enhancement effect comes mainly from the super-periphery wing control, or from the projection of the jet ejection

in the directions of the propelling force and the lifting force. Based on the state-of-the-art engine performances, a reduction of 10% in engine thrust will result when a jet stream of C_{μ}=0.01 is induced from the engine's gas compressor.

FOREIGN TECHNOLOGY STUDIES ON EXTERNAL STORE SEPARATION /27

BY KUAN-MING HSU AND I-TSAI KUO

Trajectories of the released external stores are defined by quite a number of complicated factors. Not only the geometric configuration; aerodynamic characteristics; inertial torque; weight and launch velocity of the store have to be considered, but also the flow field around the attachment point. The interference between the store and other stores may have to be taken into account. It is very difficult to try to understand the interrelationships between these factors and the trajectories of the released stores, no matter if pure theoretical computations or experimental methods are adopted. This paper will introduce some of the major techniques employed in this area of research as well as their latest developments.

PURE WIND TUNNEL EXPERIMENTAL METHOD

For a long time, the most preferred method to perform external store release research was to conduct direct free-release experiments in the wind tunnel. That is to attach the model of the external to the launch position on the aircraft model through a set of complicated release mechanisms. The store is then separated after the flow field in the wind tunnel becomes steady. Trajectory of the released store movement is simultaneously detected and recorded. The model of the store is retrieved by the safety net downstream of the experiment section. This method requires a careful design of the launch mechanism and large amount of adjustments and calibrations of the model. The most important of all is to make various store models satisfy the rule of dynamic similarity according to various experimental requirements. For example, the Mach number, the Reynolds number, the Froude number, etc.

Generally speaking, for release experiments with M $\pm$ 0.5, the Mach number similarity rule can be ignored. However, the similarity of the geometric external configuration has to be satisfied. The similarity of the Reynolds number has to be maintained. Especially important is that the Froude numbers (ratio of inertial force to gravity) of the model and the real entity must be equal.

For higher velocity (transonic, supersonic) release experiments, the method of light-model which only concerns the similarity of the Reynolds number yet not the Froude number can be adopted. Here because the gravity similarity is omitted, thus the acquired trajectory can not be very accurate. Its deviation can be empirically adjusted using theoretical analytic means. Other approaches can also be employed in this method; for example, a large power electromagnetic field can be used to simulate the gravitational field. Technically, it is very difficult. Costwise, it is very expensive. Some other people use the so-called heavy-model method in the high speed release experiments which simulates the Mach number and the Froude number simultaneously. The experimental techniques as well as model manufactures are both very difficult. Relative velocity of the external stores to the aircraft can not be accurately simulated. Therefore, only light weight and/or small density objects such as an empty external tank, light missile and rocket hooking mechanism can be simulated with this release experiment.

The most frequently adopted high speed release experiment method now is between light and heavy model methods. First the Mach number similarity is achieved, influence of gravity and relative velocity are then taken into account, thus alleviating the difficulty.

The recording of the release trajectories depends either on frequent-flashing detection method or high speed filming method. The former one uses three cameras to take pictures of the release trajectory from front, top and side. A frequent-flashing sensor is used to enhance the pictorial resolution effects. But for those observations of trajectories with violent changes, high speed filming becomes necessary (due to the interference of the light source this method can not be used simultaneously with the frequent-flashing sensors). Trajectories are recorded from three different angles with the speed of 3000 frames/second. Any minor change of the trajectory will be captured for accurate analysis.

The model is under a state of total freedom in the free-release method. Overall conditions are simulated (there is no interference of support). The flow field is more realistic. Configurations of the external store are adaptive (for example, the

non-stable aerodynamic configuration of a bomb without tail segment). Trajectories are direct for observation, articulate, yet the release mechanism is more complicated. Release trajectories are hard to control, models are easily damaged. Sometimes the wind tunnel is threatened. Experimental techniques and model manufacture are extremely difficult, expecially in the high-speed experiments. Another point should be noted:that release when an aircraft is in a horizontal state is difficult to simulate.

WIND TUNNEL AND COMPUTATION COMBINED EXPERIMENTAL METHOD

THE GRID MEASUREMENT METHOD The free-release method can only provide direct qualitative results. Thus, studies of influences of a number of important parameters on the trajectory are restricted greatly. The grid measurement method has gradually been developed which combines the wind tunnel study and computations. This development was proceeded with the improvement of the testing technology of small adaptive scales. The method has the following procedures: 1. A certain release zone is defined near the attachment point of the carrier craft in a wind tunnel study. A number of grids are then defined in x, y, z directions according to different pace (pace is defined according to analyses). 2. Store model with internal adaptive scale passes through each grid point under specific sequence and position pace while the orientation (angle of attachment, angle of skid detection, etc.) is specified. 3. Relevant aerodynamic loads exerted on the model are measured at each grid point. Because they are relatively independent therefore, the loads not only include the forces exerted on the model itself but also the interferences from the carrier craft. 4. Change the orientations of the model and repeat the above measurement. A matrix of aerodynamic coefficients corresponding to each grid point and under every orientation can thus be acquired. 5. All coefficients can be input into the computer programs of motion-equation solution-finding sequence. The release trajectory of the store can be computed. Studies using this method can be directed towards the influence of such parameters as the store attachment angle, location of center of gravity, launch force, and load characteristics on the release trajectory. Because no

gravitational simulation is required, thus on a model can be calculated all the necessary data of release trajectory for the same model yet under different mass distributions. An enormous workload on model preparations and repeated wind tunnel experiments can be saved. Even so, however, because the trajectory is not known at the beginning, therefore, locations will have to be chosen from a vast amount of possibilities. The measurements and computations involved are still awesome. Tens of thousands of data points need to be treated generally. The two weaknesses of this method are that first the relative speeds and that second loads measured on the store are interfered with by the end-support mechanism.

THE TRAJECTORY CAPTURE METHOD The trajectory capture method is further developed in order to alleviate the experimental and computational workloads in the grid measurement method. The essense of this approach is to link all measured aerodynamic loads and directly changing parameters of motion/orientation with the computer. Once the aerodynamic load of the model at initial orientation is obtained, the computer will calculate the corresponding orientation of motion, and the model will then be adjusted according to these parameters to this orientation as the next status. Aerodynamic loads under this next status are obtained for the computer to calculate the subsequent orientation..... This process is continued until the complete release trajectory is obtained. If measured result deviates too greatly from the calculated value, one can change the pace and redo the measurement. Workload, of course, will be greatly reduced compared with the grid measurement method. Time is saved while accuracy is enhanced. The mechanism involved, however, is more complicated. Experimental expense is also greater. Every single experiment yields only one curve. The problems of end-support interference as well as relative speed between store and carrier craft are not solved either. Even under all these conditions, the trajectory capture approach is considered as the more practical method among all applicable experimental methods for external store release studies. It has been widely employed in many countries. The Arnold Engineering Development Center started research of this method as early as 1968. They have successfully

developed an advanced sequenced testing system. The system is now extensively used in 4T, 16T large scale wind tunnel release experiments. France has also adopted this method to conduct experiments of the launching of AS30 missiles from Jaguar fighters. The experimental results agreed very well with actual flight tests. ONERA has officially been using the trajectory capture method to study the store release problems since 1977. The Gortingun Aerodynamic study center of Federal Republic of Germany's Aeronautic and Astronautic Research Institute has been developing the grid measurement method as well as the trajectory capture method on its transonic wind tunnel.

"INFLUENCED FUNCTIONAL METHOD" CURRENTLY BEING DEVELOPED

The above two methods depend heavily upon wind tunnel studies. In order to obtain one valuable store release trajectory, it is often necessary to conduct extensive experiments under various aircraft-external store-flight condition combinations, thus making the expense of experiments extremely high. For many years, people have been devoting themselves to look for a simpler approach, hoping to be able to use experimental data of an external store to estimate another external stores result under the same status. The key point of this method lies in the possibility of using either experimental or theoretical computational schemes to estimate local flow field characteristics around the carrier and also the functional relationships between the forces and torques at the frontal, middle, tail sections of the store and local aspect angles. The flow field is complicated because of the mutual interferences between the carrier and external store. The flow field changes considerably along the direction of gas flow around the external store (i.e. the local effective aspect angle). The influenced functional method is a recently developed approach which is relatively accurate to estimate the aerodynamic characteristics for external store release studies based on the above theory. This approach uses the measurements of one store's aerodynamic characteristics under the carrier to estimate other stores' aerodynamic characteristics in the similar carrier/flight conditions. Quite a lot of experiments under various carrier/external store/flight condition combinations can be eliminated. Although this method can be used only for supersonic

studies, yet by principle it should be appropriate for studies over other velocity ranges.

BASIC ASSUMPTION This method assumes that the normal force and torque exerted on the external store within a non-uniform flow field could be expressed as a function of local aspect angles and influenced coefficients along with the external store:

$$C_N: \sum_{i=1}^{N} A_i(\alpha - \alpha_0)_i$$

$$C_m: \sum_{i=1}^{N} B_i(\alpha - \alpha_0)_i - C_{m0}$$

Where A_i, B_i are the influenced coefficient of C_N and C_m for the ith segment of the external store respectively, α is the local aspect angle. α_0 and C_{m0} are the non-raised aspect angle and non-raised torque coefficient of the single external store respectively.

BASIC STEP 1. First calibrate the influenced coefficients A_i and B_i of the external store. This is achieved by passing the store with internal adaptive scale which is being calibrated through a known non-uniform flow field in the wind tunnel against the direction of flow. Forces and torques measured are recorded. According to the experiences of AFWAL/Grumann of the United States, use a flat plate with inclined angle or rectangular body to generate a simple binary inclined wave flow field. This flow field can be used to measure accurately the forces and torques on the external store. Using the flow field generated by the flat plate with known local aspect angle distributions, one can measure then the normal forces and torques. From previous equations, one can then find the influenced coefficients A_i and B_i. Figure 1 shows the distribution of A_i of an external store model with triangular fins. The model was passed through a supersonic wind tunnel at Mach 1.89; the flow field had a four-degree inclined agitated wave. The experiment was conducted by USAF Laight Air Force base. They have also conducted similar experiments with the Mach number range 1.5 to 2.3. Results showed that the A_i and B_i coefficients acquired using this method are satisfactory.

2. Measure the influences by the flow field of the carrier, define the distributions of local aspect angle, passing the

external store which has been calibrated by the previous method through the flow field along given line of attachment point under carrier wings. Measure also the normal forces and torques. Then, using the basic equations (with known A_i and B_i), one can find the distributions of local aspect angle along the external store. Figure 2 is the result obtained by passing the external store under a certain position line of a supersonic fighter wing. The local distributions of aspect angles are shown. Grumann's supersonic tactic fighter model was used in this experiment. Model ratio was 1:27. Distance from fighter axis shown in the figure is relative to the full scale condition (unit in inch). Obviously, repeating similar measurements under different positions under the wing will generate many distribution curves of the local aspect angles.

3. Finally, if the aerodynamic characteristics of another external store under the same fighter wing are desired, then through the "calibration", one can acquire the A_i and B_i. Using the local aspect angle distribution obtained by above method, substituting into basic equations, then the force and torque exerted on this specific store under the influence of flow field of the carrier can be directly found. With all these data, the equations of motion can be solved to yield the release trajectory.

We can see from the above statement that the key point of this method is to calibrate two kinds of external stores to define the influenced coefficients A_i and B_i. However, it has also been found under many situations that the "calibration" can be substituted by theoretical calculations, which is often more economic. The results obtained are reliable. Also, there is no consideration of the secondary effect generated by the interference of the external store itself to the carrier/store flow field. Some experimental analyses have shown that the secondary effect on the final measured forces and torques are less than 20% within the distance of one diameter from the wing.

EXAMPLE OF ACTUAL USES In order to prove the applicability of the functional method, the USAF Laight aerodynamic laboratory has conducted comparison tests using two sets of stores. One set is shown in figure 3 with two stores with and without flaps. They

have been tested under the same carrier. The experiments were to test the properties of the stores. The tests included top, botto left and right different positions of external store conditions, that is, to use the experimental results of the store without flaps to estimate the aerodynamic properties of the one with flaps. Reverse calculations were also done. Two kinds of results have been compared with the results obtained from pure wind tunn experiments. They have been found to agree very well.

The second set of models is shown in figure 4 to be an advanc aircraft carried cruise missile, with triangular flaps, reversed Y-shaped tail and triangular cross-section shaped body; the other is a cylindrical shaped with cross tail regular missile. Research were conducted with the similar steps as above. Final results showed that even the two missiles varied quite a lot in their external shapes, yet the final estimations were still very close to these acquired from pure experimental methods.

NEW DEVELOPMENT With the inspirations of the previous metho there is now a pure theoretical influenced functional method bein developed. For certain stores without very complicated external configuration, the calibration as well as the aerodynamic properties between the store and carrier interference can all use theoretical analysis instead of actual lab experiments. Calculations can be achieved on the computers. The major purpose of using theoretical computation is to provide the designer a means to decide in the preliminary design phase the configuration of the store. Therefore, a large amount of wind tunnel experiments for the purpose of choosing external store configuration can be eliminated. This has aroused extensive interests. Practical application programs ranging from supersonic to sonic to higher transonic are being or have already been formulated.

Figure 1

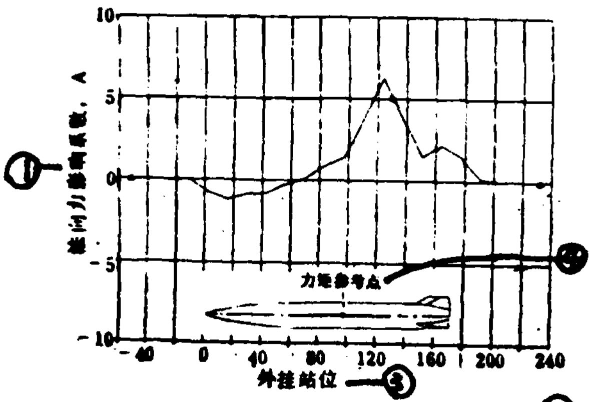


图 1 典型的用外挂物校测得到的Ai分布图

1. Influenced Coefficient of Normal Force A
2. Figure 1 Typical A_i Distribution Obtained Using Calibration Against External Store
3. Store Position
4. Reference Point for Torque

Figure 2

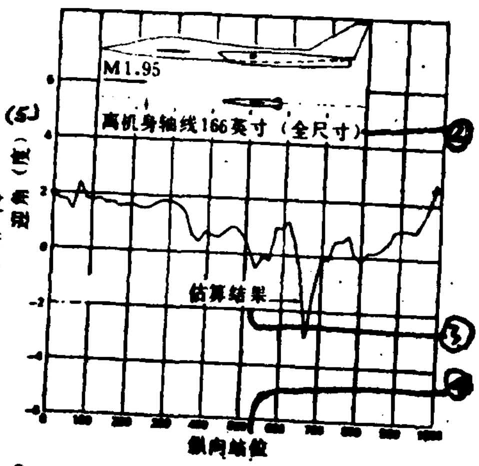


图 2 通过影响函数法测得的局部迎角分布图

1. Figure 2 Local Distribution of Aspect Angle Obtained Using Influenced Functional Method
2. 166 inch from axis (full scale)
3. Estimated Results
4. Vertical Position
5. Aspect Angle (Degree)

Figure 3

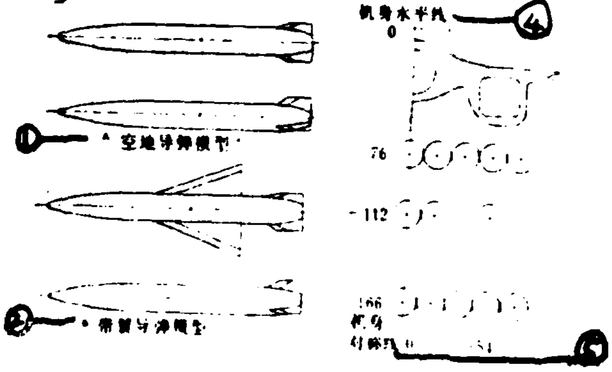


图 3 两种不同外形的外挂物外形和外挂位置图

1. Model of Air-to-surface Missile
2. Model of Missile With Flaps
3. Figure 3 Two Kinds of External Store With Different Configurations and Positions
4. Fuselage Horizontal Line
5. Fuselage Line of Symmetry

Figure 4

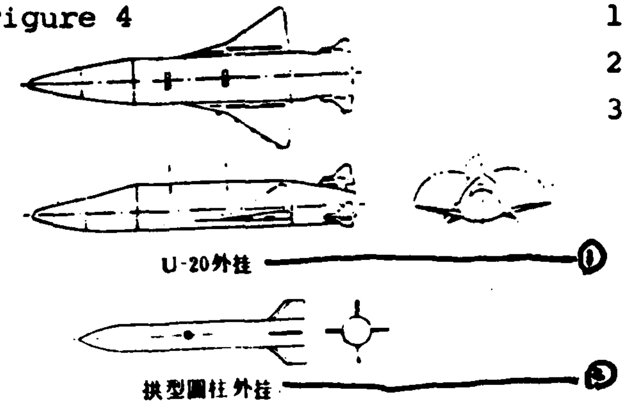


图 4 两种外形相差最大的外挂物外形 3

1. U-20 Store
2. Cylindrical Store
3. Figure 4 Configurations of External Store With Major Difference

STEALTH TECHNOLOGY:CURRENT DEVELOPMENT AND FUTURE PROSPECTS

BY CHIEN HUANG

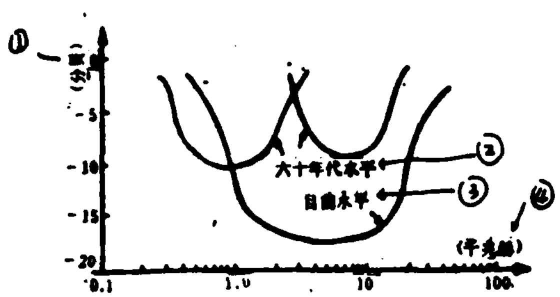
Stealth aircraft development is an important military application being carefully watched worldwide. Practical design will soon be released. We have reported some related technology of stealth aircraft. This paper emphasizes the estimates of current status of development and future prospects.

STATUS OF CURRENT TECHNOLOGY

1. Radar Cross Section

Radar cross section is a parameter to measure the magnitude of reflected electromagnetic energy by the aircraft. It has the dimension of area (m^2). The radar cross section, however, has no direct relationship with the actual surface area of the aircraft, under the working wavelength of microwave radars. It is very easy to work out a radar cross section of only $0.5m^2$ for a 20-meter long aircraft. Radar cross section is related only to the configuration, material and fuselage of the aircraft and the frequency and polarization of the radar.

Status of current development of the stealth technology is: average radar cross section is smaller than similar regular aircraft by 15 to 20 db within ± 45 of front-end position, i.e., a reduction magnitude by an order of 2. It is projected for the fightercraft of the year 2000, average radar cross section will be reduced by 30 db when compared to similar fighter aircraft, i.e., an order of 3 reduction. The following table listed several radar cross sections of typical aircraft .



附图 散射衰减的频带扩展 ← ⑤

1. dB
2. Performance status of the 60's
3. Performance status now
4. kMHz
5. Figure: The enhancement of reflected decay frequency bandwidth

We know that the reduction of detection range is related with the reduction of radar cross section to the fourth power. If the reflected wave is to contend with on-board interference, then the reduction of detection range is to be governed by the square-root equation. Obviously, the threat of stealth is much more severe in the latter case. Assume the average stealth effect currently to be 15 db (a conservative estimate), i.e., radar cross section is reduced by a factor of 31.6, then detection range will be 42% of original distance. If under interference, it will be only 18% of original distance. These numbers clearly indicate that the designers of surface-to-air interception systems must carefully take the characteristics of stealth aircraft into design consideration. Otherwise, with the appearance of these stealth aircraft, the total defense system will lose its effectiveness.

2. Frequency Bandwidth

Earlier a parasitic type energy-absorbing layer could achieve a reduction of 10 db, yet the disadvantage of the technique was the limited frequency bandwidth. For instance, a 10 db reduction could be achieved with a 60-cm wave length, however, when the wave length was expanded to 10 cm, the reduction was only 3 db. The performance has been improved by expanding the adapted decay frequency bandwidth of the layer material, removal of the strong-reflection center point and special design of the dampers. General frequency range now is 1 to 20 kMHz. The attached figure depicts the comparison of past and current frequency range.

TABLE TYPICAL RADAR CROSS SECTION FOR AIRCRAFT (WAVE LENGTH: 3 CM)

	Regular Aircraft		Stealth Aircraft			
Aircraft type	MIG-15	B-52	B-1B	ATB	F-25	ATF
Radar Cross Section (m^2)	2-3	>100	3-5	0.3-0.5	0.5	0.05-0.1

*Radar cross section is calculated as the median value within ±45 degrees of nose-front direction with 50% probability.

3. Infrared Radiation Intensity

A photoelectric compound system is now adopted for medium- and short-range surface-to-air missiles in foreign countries. Therefore a stealth effect has to be acquired against infrared radiation. The following methods are now adopted a maximum 90% reduction of radiated energy: rectangular binary nozzle design; different exhaust ducting configurations; fuel content improvements and method of injection. Thus, the tail-end infrared-tracing range is drastically reduced to 30% of the original effective distance. Effective operational ranges of surface-to-air and air-to-air missiles are decreased.

FORECAST FOR FUTURE PROSPECTS

The configuration of the stealth fighter of year 2000 has been proposed. Its average rear-direction radar cross section is expected to be as low as 0.05 m^2. Such a small radar cross section for a fighter of 20-meter length, 10-meter wing span is just unimaginable. As for infrared consideration, not only newly designed engines and better nozzle shielding techniques are being studied, but also procedures to control surface temperatures are extensively researched. Therefore, an infrared tracer with narrow working bandwidth will no longer be able to pick up such characteristic signals.

Current approaches to arrive at the goal of being "stealth" can be summarized as: lower cross-sectional aerodynamic configuration; engine design with low infrared registration; and structurally energy-transparent-absorbing materials. People are still looking for more new approaches, for example, methods of damping effect, that is, to engrave more grooves on the surface of the aircraft and stuff the grooves with insulation materials. This change will not affect the aerodynamic configuration, but will effectively change the electrical current distribution on the surface. Grooves can also be connected with dispersed or concentrated parametric resistent capacitor components, thus to realize low electromagnetic radiation to specific directions. Another example is the biological studies. An occasional study of

the radar cross section of birds indicated that although the body sizes of seagull and turdidae are similar, yet the radar cross section of a seagull is somehow 200 times greater.The bee's body size is smaller than the sparrow's, yet its radar cross section is 16 time greater. Such interesting findings pointed to the incorporation of similar studies.

Countermeasures always exist. The study of stealth techniques have been in development for more than 20 years. There is no doubt that counter-stealth measures must also be in progress. However, new theories of electromagnetic reflection/scattering and configurations of radar systems are constantly involved, thus restricting the public distribution of these documentations. For example, current stealth technologies are mostly aiming at suppressing rear-direction reflection. These technologies may be compromised by dual-based or multiple-based radar configuration. Another example is the theory of harmonic reflection proposed by some other researchers. The theory points out that no matter what the material composition of the target is, it is always immersed in a certain kind of medium which is permeable to the penetrations of waves. When the targets are activated by waves (sound wave, electromagnetic wave and elastic wave), the reflected waves will always be able to be detected by sensitive receivers. Therefore, the elastic mechanics and electromagnetic reflection theories are combined. A new radar detection theory may thus be generated. It will then be used against the stealth aircraft. To summarize, the competition between stealth technologies and anti-stealth technologies will enhance the progress in radar, aerodynamics and engine theories/design to come up with new aircraft..

Stealth technology development is still in its preliminary phase. It is a cumulative marginal scientific technology encompassing electromagnetic reflection; infrared radiation; aerodynamics and vehicle composite material sciences. Experiences have proven that independent studies of wave-absorbing materials, wave-transparent materials and composite materials are unsuccessful. Foreign countries are now cultivating a group of graduate students

and engineering technical personnel with overall marginal scientific knowledge. Documentations and text materials in this regard are gradually emerging, for example, "Basics of radar cross section for aircraft design engineers" and "Targets of radar detection" etc. In this new worldwide industrial revolution era, we should pay attention to the trend of these technological developments.

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